If the results of the determinations just given and those for copper for the same range, 23°···100° C., are employed, a comparison can be made between the specific heat of pieces of certain metals (copper, iron, and aluminum) determined between —181.4° C. and 13° C. and the specific heat of the same pieces of metal determined between 23° and 100° C., by the same method.

The following table has been arranged to show this comparison :

TABLE 7.

| Metal. | Specific Heat. -181.4°···13° C., (employing liquid oxygen). | Specific Heat. 23°···100° C., (employing boiling water). | Actual difference between two values. | Percentage difference between two values. |
|---|---|---|---|---|
| Copper. | .0868 | .0940 | .0072 | 7.6 % |
| Iron. | .0914 | .1162 | .0248 | 21.3 % |
| Aluminium. | .1833 | .2173 | .0340 | 15.7 % |

It is shown by this table that the specific heat of copper, iron and aluminium between —181.4°C. and about 13°C. were found to be, respectively, .0868, .0914 and .1833, or 7.6, 21.3 and 15.7 per cent. less than the specific heat of these metals determined between 23° and 100°C.

An error of several degrees in the low temperature value (—181.4°C.) would affect the accuracy of these results only to a small amount. If, for example, the specific heat of iron for the low range of temperature is assumed to be the same as between 23° and 100°C. it would mean that an error of over 40 degrees had been made, which is obviously impossible. If there are errors in the results given above, the present indications are that they are less than one per cent.

The value of the water equivalent of the calorimeter and thermometer finally used in the calculations in all the specific heat experiments was obtained from the mean of ten determinations. The mean value was 5.87 grams.

The calorimeter was made of copper, cylindrical in form ; height, 9.75 cms.; diameter, 4.0 cms.; and weight, 35.498 grams.

The thermometer was one made by Henry J. Green, No. 8407, graduated to $\frac{1}{20}$ of a degree Centigrade, and could be read to $\frac{1}{100}$ of a degree.

C. C. TROWBRIDGE.

COLUMBIA UNIVERSITY, June 16, 1898.

### *THE FLICKER PHOTOMETER.*

PROFESSOR ROOD'S interesting article in SCIENCE of June 3d prompts me to add a few words corroborating his statement as to the ease with which the flicker photometer is handled by observers unaccustomed to its use. If the lights to be compared differ at all in color, it is probably more easy to use, for the unskilled observer, than ordinary photometers, as the following experience, among others, shows. While I was experimenting, in 1895, with the revolving disk instrument to which Professor Rood refers, two chemists, in the course of an investigation, found it necessary to compare photometrically the illuminating powers of several different specimens of refined petroleum. I placed at their disposal a Lummer-Brodhun and a Bunsen Photometer, and showed them, as a matter of interest, the newly-devised flicker instrument. The standard lamp differed slightly in color from the flames given by the oils under investigation, so that the two observers found it somewhat difficult to obtain concordant results with either of the two ordinary photometers. They, therefore, reverted to the flicker instrument, using it to check all their results, finding its use, under the conditions, more agreeable and certain than either of the others.

With the Lummer-Brodhun or the Bunsen instrument they experienced all that unpleasant sensation of uncertainty which

attends the comparison of differently colored lights; each found it hard to make readings agreeing with the other, or even to verify the other's readings. With the flicker instrument these difficulties disappeared.

As Professor Rood says, there is little or no more difficulty or fatigue in the use of this instrument than in other optical observations, the approximate setting being quickly made, and the flicker near that point being so slight as not to disturb the eye, yet being distinct enough to require no especially strained attention, unless the illumination is too feeble. I may call attention here once more to the statement in my previous paper, that the method used by Professor Rood, of keeping the photometer and one lamp stationary, moving the other, has certain notable advantages in the use of this instrument, especially in the comparison of a number of lights differing greatly in color and in brightness, in that the standard light can be kept at a fixed distance from the photometer, and all the measurements made at the same absolute brightness, insuring about the same quality of flicker, and about the same degree of sensitiveness throughout.

The arrangement, however, is obviously not so sensitive as that in which both lights are stationary and the photometer itself is moved, and probably the latter method is generally preferable when the lights are sufficiently bright. It takes a little longer to make a setting with the flicker photometer than with others, and for this reason it is not easy to use upon an arc light, where the brightness is continually changing. This difficulty, of course, varies greatly with the character of the arc.

The essence of the flicker photometer lies in this, that the two fields to be compared are presented to the eye alternately, in rapid succession, and not as in other instruments simultaneously, and side by side. There is no attempt to compare the two lights. One simply notes the disappearance of a certain recurrent sensation. It is evidently necessary that the two fields compared should fill exactly the same portion of the whole visual field, and it is desirable that the time taken in transition from one field to the other should be as small a portion as possible of the whole time of observation, in order that the retinal shock, to which the 'flicker' sensation is due, may be sharp and sudden. I am inclined to think that the latter condition is more easily and completely met by a rotating than by an oscillating apparatus.

Professor Rood's form of the instrument possesses some advantages over the rotating disk. The faces of the large prism are rigid, and the same portion of each of them is always used. A rotating disc is thin, easily bent or distorted, and there is a possibility of difference in the character of the surface of different parts, which, since the whole of it passes in review before the eye, might cause a flicker between different portions of the disk itself. A flat disc of zinc, however, to which is firmly glued a sheet of white paper, gives but little trouble, and the line separating the two fields is rendered almost imperceptible by filing thin that edge of the disk which passes in front of the eyepiece. Again, the method of construction of the disk photometer makes it impossible that the two lights to be compared should be in the same line parallel to the photometer bar, an arrangement which becomes inconvenient if it is desired to change from this to another photometric apparatus. This difficulty is avoided in the oscillatory apparatus of Professor Rood.

I may mention here a form of the flicker photometer (described at the Detroit meeting of the American Association for the Advancement of Science, but not elsewhere published) which avoids some of the difficulties of the disk form and is more convenient for ordinary photometric purposes.

A short truncated cone is made of wood, and the conical surface carefully whitened. The approximate dimensions of the cone in my apparatus are: lower base, 20 cm.; upper base, 15 cm.; height, 3.7 cm. The cone is cut in two along the axis, one-half reversed in direction, and the halves fastened together in this new position. The whole is then mounted so as to rotate about the axis of the cone, which is placed parallel to the photometer bar.

The figure represents the photometer. L and L′ are the lights to be compared.

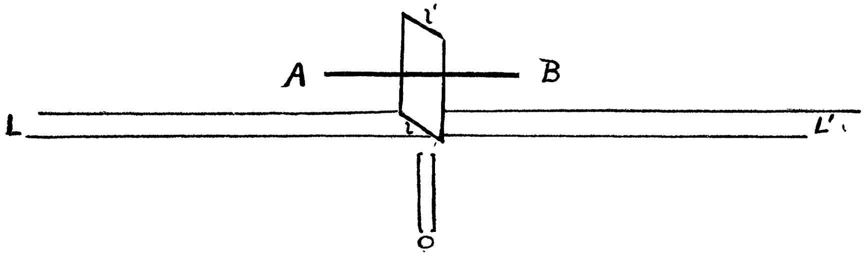

FIG. 1.

The cone, cut and reversed as described, revolves about the axis AB. The plane of division of the cone, as the figure is drawn, passes through this axis and is perpendicular to the paper. O is the eye-tube. When the instrument is in the position shown, *l* is in the field of view and is illuminated by the lamp L, but when the cone has made one-half a revolution *l′* is seen, which is lighted by the lamp L′.

While this instrument is compact and convenient for most photometric measurements, the disk form is superior for the comparison of pigments, as one of the fields consists simply of a card, which can be removed in an instant and replaced by another. Thus differently tinted papers can be easily compared in succession with the revolving disk, which may be of any color, but which in practice is generally white or gray.

I do not know whether it has been generally remarked that Captain Abney, in his careful measurements of the distribution of brightness in the spectrum, seems to have used a method of observation closely akin to the flicker method, though apparently without perceiving its definite character or possibilities. His well-known color-patch apparatus places side by side two differently colored fields, the brightness of one of which can be rapidly varied by opening or closing the apertures in revolving sectors. I quote the following from his Tyndall lectures, delivered in 1894:

"By gradually diminishing the range of the 'too open' to 'too close' apertures we arrive at the aperture where the two colors appear equally bright. *The two patches will cease to wink at the operator*, if we may use such an unscientific expression, when equality in brightness is established. This operation of equalizing luminosities must be carried out quickly and without concentrated thought, etc."

It seems probable that Abney, throughout these measurements, applied himself not so much to a careful comparison of the brightness of the two colors involved as to reducing to its faintest condition this *wink*, which differs little in its nature from a flicker.

FRANK P. WHITMAN.

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*BIOLOGICAL SURVEY OF LAKE ERIE.*

ON July 1, 1898, the U. S. Commission of Fish and Fisheries will inaugurate a biological survey of Lake Erie, under the direction of Professor Jacob Reighard, of the